A New Smart Sensing System Using LoRaWAN for Environmental Monitoring

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***Abstract*—An increasing interest is drawn to environmental monitoring applications such as weather monitoring, asset monitoring, and smart agriculture. This paper proposes a new Internet of Things (IoT) sensing system for environmental monitoring. The system consists of wireless sensor nodes, communication network, and data visualization and storage cloud. The wireless sensor node is powered by a solar panel and RF energy harvester (in case solar energy is not available) to avoid changing batteries frequently and save the maintenance cost. It has a compact size and can sense many environmental parameters, such as temperature, air pressure, humidity, loudness, and air quality. A low power communication technology named LoRaWAN is used to connect different sensor nodes for a wide area coverage. Finally, a cloud server named Cayenne myDevice is employed to receive, present and store measured data. This smart sensing system with energy harvester can be used for many other IoT applications.**

Keywords—cloud applications, cloud communications and networking, IoT applications, smart sensors, smart systems.

I. Introduction

Real-time environmental data (e.g., temperature, humidity, lightness, wind speeds, and wind directions) is needed in different applications such as weather monitoring/ forecasting, asset monitoring, smart city, smart agriculture, aviation, and load prediction [1, 2]. Climate changes have received much attention recently, which makes it an active and hot research area. To statistically study the climate change and the impacts of the human activities on nature environment, we need to collect real-time data like rainfall, temperature, CO_2, wind speed, and air quality from various places over the time [3]. Also, the clean and environmental-friendly renewable energy is now penetrating the power grid at an accelerating speed [4-6]. However, renewable energy generated from solar farm and wind turbine is highly weather-dependent. Weather stations should provide accurate, and real-time metrological data to predict the load and achieve smart control in the modern power grid [6]. To realize smart agriculture, different sensors should be deployed over a wide region to monitor the crop and environmental conditions in the farm [7-9].

A low-cost Internet of Things (IoT) based smart sensing system is a promising solution to provide real-time data to meet the requirements of different environmental monitoring applications [10]. There are some design challenges of the sensing system to be overcome, such as developing a low-cost and compact sensor node, a large-scale and robust transmission network, and a real-time data visualization system. To improve the deployment flexibility, the battery is the power source to provide energy to the sensor node where the battery replacement should be reduced to save costs and maintain the performance of the overall sensor network [11].

A lot of research has been undertaken in the development of modern environmental sensing systems. Remote sensing has become an effective tool to make observations of weather conditions over a large scale [12]. However, the low temporal and spatial resolution limits the wide application of remote sensing [13]. To achieve more precise environmental monitoring, various weather stations are developed to measure temperature, humidity, air pressure, wind speed, wind direction, etc. However, fewer research has been focused on the energy consumption of weather stations [14, 15]. The cost of commercial weather station is typically not cheap. In addition, some weather stations do not have cloud integration so that the measured data is less accessible from the user end [2].

This paper proposes a new design of smart environmental sensing system with self-powered sensor nodes, LoRaWAN communication network, and real-time data accessible cloud. The wireless sensor node is embedded with a sleep mode control to save operating power. Moreover, a hybrid energy harvesting powering method is developed for the sensor which is a combination of a 3 W solar panel and a wireless ambient electromagnetic energy harvester. The total cost of one sensor node is around 100 pounds. LoRaWAN is used to provide a wide range connectivity for the sensor nodes. The real-time data gathered from the sensor nodes can be easily monitored and obtained from a Could App (Cayenne).

The rest of this paper is organized as follows. Section II explains the system architecture of the environmental sensing system. In Section III, we present the prototype of the sensor node in the sensing system and illustrate how three sensing devices are deployed to carry out environmental monitoring activities. The measuring results of the sensing system are given, and the coverage and the energy performance of the sensor nodes are evaluated in Section IV. Finally, conclusions are presented in Section V.

II. System Architecture

A. Hardware

The wireless sensor node is composed of four units, which are the Power Management Unit (PMU), the sensing unit, the microcontroller unit (MCU), and the communication unit, as shown in Fig. 1. The sensors can measure different environmental parameters, and the MCU can read the measured data. The MCU will process the raw data and transfer the data obtained from the sensors into a single payload which is ready to be sent to cloud. Then, the LoRaWAN communication unit can transmit the payloads

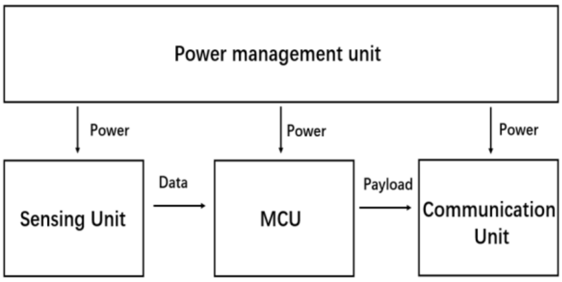


Fig. 1. The architecture of the wireless sensor node.

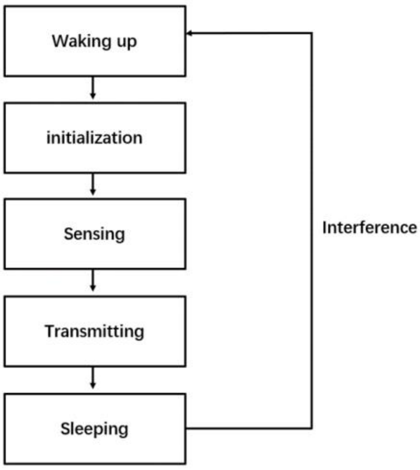


Fig. 2. Software working diagram.

containing the value obtained from the environmental sensors to the LoRaWAN gateways. The wireless environmental sensing nodes will be connected to the gateway by using LoRaWAN protocol to form a wireless sensor network. To set up the LoRaWAN based environmental sensing network, an eight channels LoRaWAN gateway is used to provide the LoRaWAN coverage to the sensor nodes.

B. *Software*

The wireless sensor node is developed using the Sodaq Mbili which is based on the Arduino development board. To program the sensor node and LoRaWAN transceiver, commands are written by using the open-source Arduino Software (IDE). The code for the node plays an essential role to guarantee the environmental sensing system can work properly. It needs to put the MCU and the sensors into sleep mode to save energy and wake up them by using the interference generated by the real-time clock to collect environmental data. The working diagram of the software is displayed in Fig. 2.

C. *Cloud*

The gateway will upload the received message from sensor nodes to a cloud platform, namely The Things Network (TTN). The working diagram of the connections between the sensor nodes, gateway and, cloud is displayed in Fig. 3. The gateway should be registered to TTN to transmit the received data from the sensor nodes to the TTN console. Firstly, the gateway needs to be registered in the TTN platform, and the TTN will automatically generate the gateway ID and the gateway keys. The gateway ID and the gateway key should be manually entered to the host board.

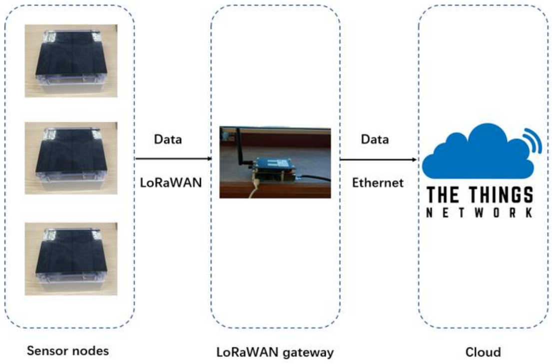


Fig. 3. The architecture of the environmental sensing platform.

Then, the gateway can forward the received message from sensor nodes to the TTN. Another cloud named Cayenne is integrated with the TTN to present and store measured environmental data.

III. Hardware Prototype and Deployment

A. *Hardware Prototype*

The Sodaq Mbili uses a Microchip ATmega 1284p as its microcontroller (mother board) which has 128kB ISP flash memory with read-while-write capabilities, 16kB SRAM and a real-time counter. The MCU is designed to support low energy applications, and the current consumption is 0.4 mA in the active mode and 0.6 μA in the power saving mode when it operates at 1MHz, 1.8 v, 25 °C. The real-time counter embedded in the MCU can be used to switch the device from a wake-up mode (on data transmission) to sleep mode in order to reduce the power consumption during the normal operations. The LoRaWAN communication module for the sensor node is RN2483. The instant transmission current consumption of the RN2483 is 44.5 mA, and the idle current consumption is 3.1 mA when the transceiver is connected to a 3.6V power supply. The operating frequency bands of the transceiver is 863 - 870 MHz for the EU standard.

There are multiple sensing functions integrated in the device, which are light, loudness, air-quality, temperature, pressure, and humidity (TPH) sensor. All the sensors are connected to the mother board by using grove connections for power and data transmissions. The main feature of the sensor node is that it can be self-powered so that avoiding frequent manual battery replacements. To realize this function, a 3W solar panel, a wireless energy harvester [16], and a 6000 mAh Lithium Polymer (LiPo) battery are used to provide energy. The PMU of the sensor node has two Japanese Solderless Terminal (JST) ports to link the solar panel and the LiPo battery. Since the harvested energy from the solar is time varying and weather dependent. The battery is used to provide a steady 3.7 V output voltage to ensure that each module of the sensor node can work properly. The solar panel with a maximum output voltage of 6 V is used to charge the LiPo battery under the control of the PMU. During darkness or bad weather conditions, the RF energy harvester can also supply a small amount of energy (e.g., in the μW range) to maintain the entire system.

The wireless sensor node is held in an IP66 dustproof and waterproof box in congestion with a 3D printed base, as shown in Fig. 4. The box has a transparent cover which is made of polycarbonates (PC) and an opaque base which is

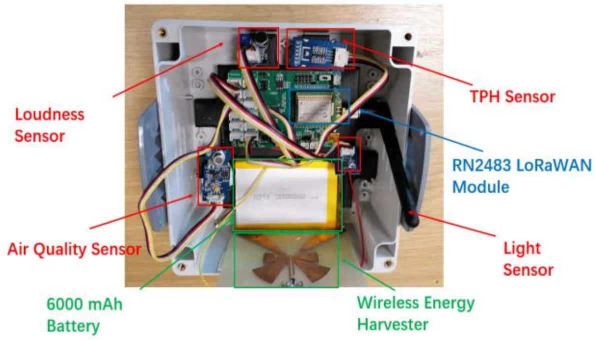


Fig. 4. The inside look of the sensor node.

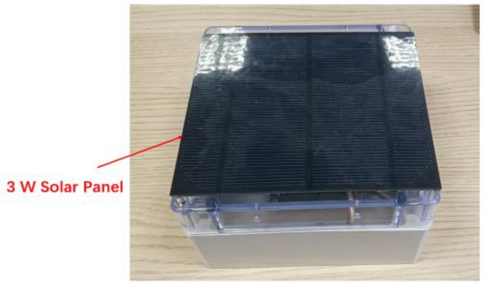


Fig. 5. The outside look of the sensor node.

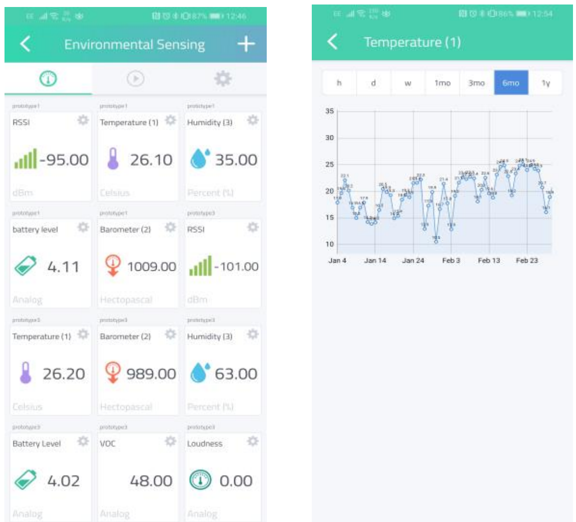
made of acrylonitrile butadiene styrene (ABS). The 3D printed black base is placed at the bottom of the sensor box, which is used to mount sensors, the battery, and the Sodaq Mbili board. The sensor box is sealed to an IP66 standard to prevent the rain. The inside look and the outside look of the sensor node are presented in Fig. 4 and Fig. 5. The overall cost of the sensor node is only GBP 112.59.

The indoor LoRaWAN gateway is built using the Raspberry Pi 3 and the RAK831 concentrator module. The RAK831 is a multi-channel high-performance transmitter and receiver module designed to receive up to 8 LoRa packets with different spreading factors at the same time on multiple channels. It operates at 863 MHz to 870 MHz frequency band and supports both the LoRa and Frequency Shift Key (FSK) modulation techniques. A Raspberry Pi 3 acts as a host board to control the RAK831 frontend. A 5V and 2A power supply needs to connect to the Raspberry Pi 3 to activate both the Raspberry Pi 3 and the RAK831.

B. Deployment

Three wireless sensor nodes have been deployed across the University of Liverpool as a pilot trial for more than three months sensing up to 5 environmental parameters. They were placed in both indoor and outdoor conditions, as displayed in Fig. 6. To make each sensor node become a standalone device powered by using sustainable energy, the device is placed near the window in indoor circumstances to obtain enough sunlight. The LoRaWAN gateway is an indoor gateway, and it is placed in a typical office, as shown

Fig. 6. The deployment of sensor nodes and the LoRaWAN gateway. (a) The sensor node in indoor condition 1; (b) The sensor node in indoor condition 2; (c) The sensor node in outdoor condition; (d) The LoRaWAN gateway in indoor condition.



(a) (b)

Fig. 7. The results of the environmental sensing system. (a) The overall measured environmental parameters of three sensor nodes; (b) The measured temperature of one sensor node over two months;

in Fig. 6. The gateway is placed near the window facing the city center to cover more end users.

IV. Measured Results and Analysis

A. Measured Results

All the measured environmental data will be stored and presented in myDevice Cayenne cloud, and the measured data can be accessed from both the web page and the mobile application. Fig. 7 is an example of the results obtained from the environmental sensing system through the mobile application. All these parameters are received and displayed in real time, as shown in Fig. 7 (a). In this figure, we present an example of the historical measured temperature over two months stored in cloud. The users can easily obtain access to the measured results from the registered sensors which were deployed in different locations.

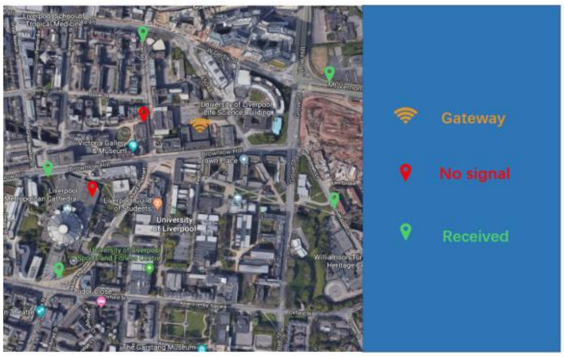


Fig. 8. The coverage test of LoRaWAN.

B. Coverage Analysis

To do the coverage test, we have firstly placed the gateway on the first floor of the building, which is indicated by the orange icon (see Fig. 8). The position labelled by using the green icon can receive the LoRaWAN signal, and there is no signal at the place marked by the red icon. The two places with no signal are due to the obstruction of the tall buildings. Based on the test, it can be found that the LoRaWAN can achieve better coverage with line-of-sight, and the obstruction can block the signal. Therefore, the deployed position of the gateway should be carefully chosen to avoid obstructions and maximise the coverage.

C. Energy Performance Analysis

The energy remained in the battery of the sensor node was continuously monitored over three months, starting from December 17th, 2018. In this test, the output voltage level of the battery is used to determine the remaining energy in the battery. The overall battery voltage level trend drops at the beginning and goes up subsequently. The main factor which could affect the amount of harvested energy from the solar panel is the weather condition. The solar panel can be used to charge the battery in sunny days, and the sensor node will consume the energy stored in the battery during cloudy and rainy days. Instead, the wireless energy harvester can provide steady energy output up to 40 μW for the input RF power level of -10dBm, and less than 5 μW at the ambient signal levels below -30 dBm. From Fig. 9, it can be found that the battery voltage level goes back to the origin position after three months observation. It demonstrates that the solar panel can be used to provide energy to the sensor node, and the device can then be a self-powered sensor node without the need of changing the battery.

V. Conclusions

This paper has presented a wireless sensing system for environmental monitoring which consisted of three wireless sensor nodes, a LoRaWAN communication network, and cloud for data presentation and storage. It has been demonstrated that five environmental parameters can be captured, transmitted wirelessly over the sensing platform, and can be freely accessed from the Cayenne cloud. In this design, the LoRaWAN communication method was implemented to provide a wide wireless connection for the sensor nodes. The solar panel and RF energy harvester were used to provide energy to the sensor node to avoid changing the battery to reduce the maintenance cost. Overall performance of the device and system has been fully evaluated and discussed. Our future work will be the large-scale deployment of the sensor network and its performance benchmarking for real world applications.

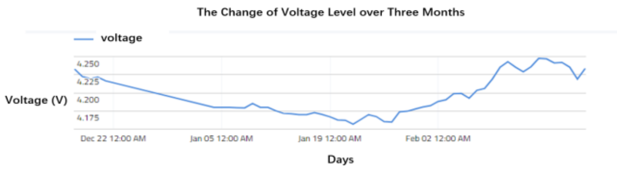


Fig. 9. The change of the voltage level in 3 months.

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